

# Developing SrRuO<sub>3</sub> for Electronic Applications

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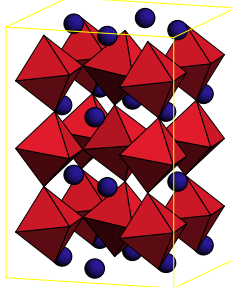
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## Motivation

Ruthenates display rich mix of magnetic (Sr<sub>1-x</sub>Ca<sub>x</sub>RuO<sub>3</sub>) and superconducting (Sr<sub>2</sub>RuO<sub>4</sub>, RuSr<sub>2</sub>GdCu<sub>2</sub>O<sub>8</sub>) properties that are very sensitive to synthesis conditions and chemical compositions

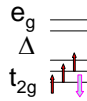
### Basic facts about SrRuO<sub>3</sub>

- Perovskite Structure: no direct Ru-Ru interaction, strong Ru-O covalency
- Ferromagnetic metal, T<sub>c</sub> = 160 K
- Magnetic moment ~ 1.6 μ<sub>B</sub> at 30 T



Orthorhombic *Pbnm* structure of SrRu<sup>4+</sup>O<sub>3</sub>

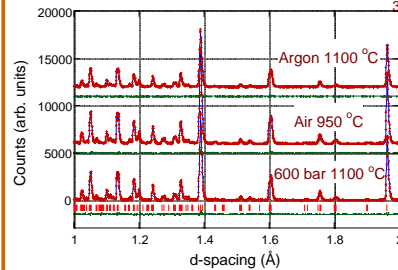
We have observed dependence of magnetic properties on synthesis conditions; discovered that deleterious Ru-vacancies suppress ferromagnetism; and found that Cr substitution for Ru offsets defects and enhances ferromagnetism and conductivity



SrRuO<sub>3</sub> was considered for application in microelectronics; We show that possibly also in magnetic recording and thermoelectric heat conversion

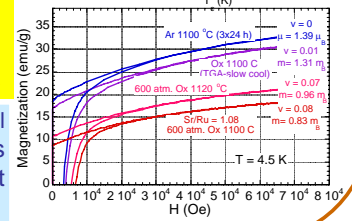
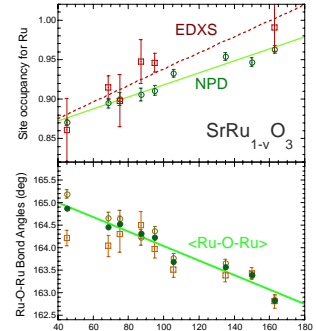
## Reduced Curie Temperatures in SrRu<sub>1-v</sub>O<sub>3</sub> Perovskites from Ru-site Vacancies

Rietveld refinements of neutron powder diffraction data at 295 K for SrRuO<sub>3</sub>

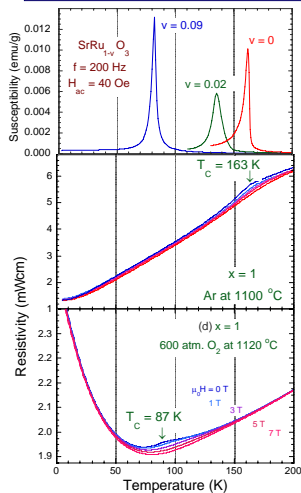


High-pressure oxygen annealing enhances formation of Ru-vacancies  
SrRuO<sub>3</sub> (solid) + v O<sub>2</sub> → SrRu<sub>1-v</sub>O<sub>3</sub> (solid) + v RuO<sub>2</sub> (vapor)

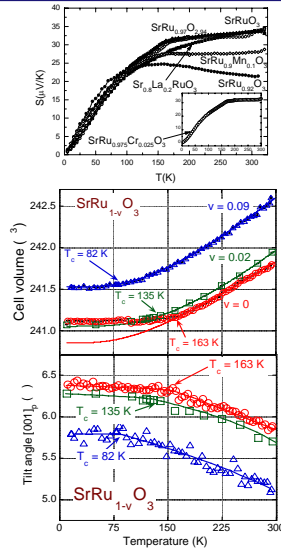
Anomalous decrease of structural distortion; Ru-vacancies suppresses ordered moment to 0.8 μ<sub>B</sub> and T<sub>c</sub> to 45 K



## Temperature Dependent Studies of SrRu<sub>1-v</sub>O<sub>3</sub>

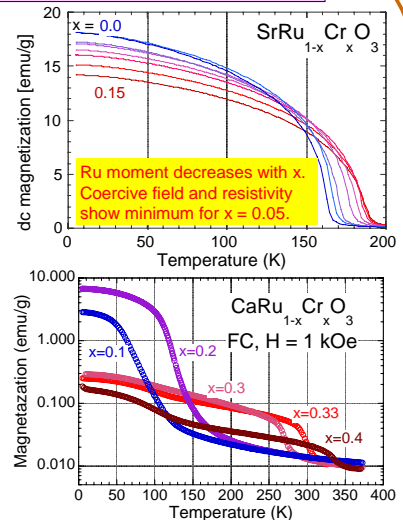
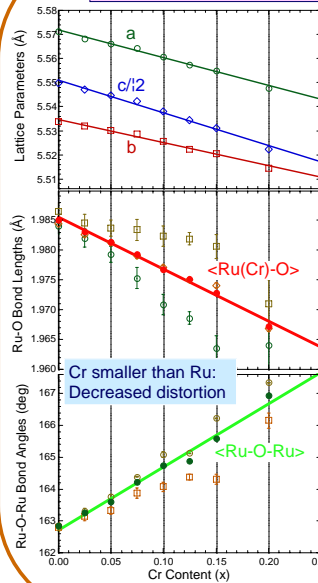


Good p-type conductor with high thermoelectric power coefficient - Thermoelectric material?



Origin of the invar effect: freezing of octahedral tilts [001]<sub>0</sub> below T<sub>c</sub>

## Improved Properties of ARu<sub>1-x</sub>Cr<sub>x</sub>O<sub>3</sub>



Double-exchange increases T<sub>c</sub> in SrRuO<sub>3</sub> and induces high-temperature ferromagnetism in CaRuO<sub>3</sub>

### Summary and Future Work:

SrRuO<sub>3</sub> has been known for half a century as a strongly-correlated ferromagnetic metal with possible application as electrode of electronic circuits. We have discovered that deleterious Ru-site vacancies that decrease T<sub>c</sub> and increase resistivity are created in SrRu<sub>1-v</sub>O<sub>3</sub> by processing under oxidizing conditions. With Cr substitution for Ru we were able to increase T<sub>c</sub> from 163 to 188 K and decrease resistivity for SrRuO<sub>3</sub> and induce high-temperature ferromagnetism in CaRuO<sub>3</sub> by using "design rules" of the synthesis and magnetic interactions developed earlier in this project. Future work will be focused on evaluating practical properties of ruthenates and further developing tolerance factor synthesis rules to include dependence on pressure. This work will involve "in situ" neutron powder diffraction under varying conditions of pressure and temperature to probe the important internal structural parameters such as bond lengths and bond angles. Synthesis under high-pressure will be used to verify synthesis rules and obtain novel magnetic, electronic, ferroelectric, superconducting, and multi-characteristic perovskites.

**Increase of Ferromagnetic Ordering Temperature by the Minority-Band Double-Exchange Interaction in SrRu(1-x)Cr(x)O<sub>3</sub>.** B. Dabrowski, S. Kolesnik, O. Chmaissem, T. Maxwell, M. Adveev, P.W. Barnes, and J.D. Jorgensen, *Phys. Rev. B* 72, 054428 (2005)